

# The Emergence of Consciousness in the Quantum Universe

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## ABSTRACT

It is argued that human consciousness is likely to have emerged during the self-consistent evolution of the physical universe, through the gradual accumulation of biological entities' ability to tap into the intrinsic non-deterministic potentiality in the global nonequilibrium phase transitions occurring continually in the quantum universe. Due to the fact that the matter and energy content participating in these global phase transitions is a continuum, there are in effect infinite degrees-of-freedom in the substratum, which invalidate the usual deterministic laws of the mechanical evolution, and allow chance factors to appear in the emergent properties of resonantly-formed quantum particles, especially in the acquired phases of their wavefunctions. Such chance factors, though occurring mostly randomly during the early cosmic evolution phase, can be harnessed more "purposefully" by the biological entities co-evolving with the physical universe, due in part to the globally-entangled nature of quantum interactions. Over time, this ability to deliberately manipulate the chance factor in the fundamental level of quantum interactions gradually evolves into the free will and self-awareness of higher biological beings. The emergence of higher-level consciousness in turn greatly enhances the entropy-production ability of the biological entities, making them a powerful new form of the "dissipative structures" that nature constructs to accelerate the entropy evolution of the universe. It is further shown that complex, nonequilibrium systems (including the universe as a whole) have the innate ability to spontaneously generate ever-renewable, highly-complex structural features in response to a changing and evolving environment; therefore natural selection is not the only driving mechanism for the irreversible evolution of the internal characteristics of biological species.

**Keywords:** Consciousness; quantum measurement; quantum entanglement; Mach's Principle; dissipative structures; nonequilibrium; evolution phase transitions

## 1. INTRODUCTION

A number of researchers have previously suggested that quantum processes might be playing an important role in the generation of human consciousness (see, e.g., Penrose et al. 1993 and the references therein; Stapp 2009 and the references therein). A main reason for investigating the role of quantum mechanics in consciousness formation lies in the realization that classical physics allows essentially only deterministic evolution – meaning that the details of all future events are predetermined from the initial conditions at the formation of the universe more than 10 billion years ago. Deterministic dynamics obviously could not serve as the basis for free will, which is an important component of higher consciousness. In quantum physics, on the other hand, there is a chance factor which is revealed both through the probabilistic interpretation of the quantum wavefunction, and through the probabilistic element in quantum-measurement wavefunction collapse.

The current work continues this well-known tradition of modern thinking, but goes a significant step further in suggesting that the origin of consciousness is to be sought in the common origin of all physical laws in a globally-connected quantum universe. This new view on the origin of consciousness is based on a new conceptual view of the foundations of quantum processes (Zhang 2007), in which the origin of all physical laws and the properties of fundamental particles are sought in a form of generalized Mach’s principle. It postulates that the matter and laws in the physical universe are co-selected, and they co-evolve in a global “resonant cavity” consisting of the entire matter and energy content of the universe. Quantum measurements in this theory are global nonequilibrium phase transitions happening either spontaneously, or induced by artificially-enforced boundary conditions in the universe resonant cavity. Quantum jumps occur because the universe environment becomes unstable to the formation of new quantum “modes” under the changing boundary conditions, much like in classical systems such as microwave oscillators, which form intrinsic modes of spatial-temporal oscillations when a certain boundary condition is enforced. What distinguishes these quantum global phase transitions from classical ones is that the classical nonequilibrium phase transitions can in general be isolated in a small, finite region, whereas the quantum global phase transitions we are referring to happen in the entire universe as a whole, which explains why, for example, a given species of fundamental particle generated from high-energy reactions always has exactly the same intrinsic characteristics no matter whether they are generated in a reactor in CERN, or in Brookhaven. Another characteristic distinguishing quantum interactions from classical ones is that quantum wavefunctions are globally distributed, and are always entangled to varying degree with the wavefunctions of all the other matter in the universe, causing the propagation of their mutual influences to happen superluminally. These characteristics of quantum interactions turn out to have important implications on how a quantum-mechanically-based consciousness model oper-

ates. We will further show in this paper that, in fact, there is no clear distinction between a quantum measurement process and a unitary evolution process. Quantum processes are unified by a continuous variation of characteristics bridging these two theoretically-idealized extremes. This new conceptual model of a continuous variation of the characteristics of quantum-biological processes, coupled with other well-known characteristics governing the evolution of self-organized complex structures in nonequilibrium systems, guarantee that quantum-mechanically based biological functions (including human consciousness) do not suffer from the threat of decoherence.

An important corollary from adopting this view is that among the important drivers for biological evolution (including the evolution of consciousness), one should not only include natural selection of random variations of characteristics, as Charles Darwin had originally proposed, but also the universal tendency for self-organized nonequilibrium structures to respond directly to their changing and evolving environment.

## 2. A NEW VIEW ON THE NATURE OF QUANTUM PROCESSES

In Zhang (2007), a new ontological view of the quantum processes is presented. It is proposed that quantum (as well as classical) processes can be understood as a hierarchy of nonequilibrium phase transitions, with the lowest hierarchy occurring in a “resonant cavity” formed by the entire matter and energy content of the universe. In this formalism, physical laws themselves are resonantly-selected, which accounts for the fact that essentially all quantitative physical laws can be derived from variational principles, and a correlation exists between the invariance of transformation properties of physical systems and the conservation laws these systems obey (Noether’s theorem, see, e.g. Neuenschwander 2010). In this model the values of fundamental constants and properties of fundamental particles are determined through a generalized Mach’s principle (i.e., the numerical values of the fundamental constants are results of the content and distribution of matter and energy in the universe). The existence of a universal preferred reference frame is shown to be consistent with the relational nature of physical laws, such as the relativity theories. The superluminal nature of quantum processes in the lowest hierarchy of quantum phase transitions is shown to be able to coexist with the universal speed-of-light limit obeyed by processes in higher hierarchies.

One important issue that has been only briefly mentioned in Zhang (2007), that there is in fact not a distinctive boundary between a measurement process and a unitary evolution process, has in the intervening years been much better clarified by the author. A brief summary on this point is as follows: In the orthodox interpretation of (nonrelativistic) quantum mechanics, unitary evolution describes the evolution, according to the Schrodinger

equation, of the probability density representing a quantum system, and the driver for this evolution is often represented by a constant potential in the Hamiltonian. In this picture a quantum measurement is an abrupt interruption of the deterministic evolution of the quantum wavefunction, with the result of the measurement being, in general, uncertain, and with the probability of any particular outcome given by the overlap of the wavefunction at the start of the measurement with a new basis function determined by the particular measurement procedure.

However, for the kind of unitary evolution problems which require perturbative treatments (see, for example, Sakurai 1985), including either the time-dependent perturbation methods (to treat time-dependent potentials), or the time-independent perturbation methods (to treat scattering problems), the solutions of these problems often appear as a continuum of probability densities  $\psi(\mathbf{r})$  (which can be time-dependent as well in the case of time-varying potential), with the probability density at each spatial location having infinitely small absolute value, but accurately specified relative ratios. These perturbatively-treated scenarios, viewed in light of the new ontological theory of the quantum processes, are in fact analogous to the quantum measurement situations, in that an enforced boundary condition (due to either time-varying potential or the intruding scattering object) causes the probability distribution of the incoming wave/mode to either fast-jump (as in scattering) or slow-evolve (as in time-dependent potential) into a new modal set, and the results of either these fast or slow evolution processes are in terms of the distribution of probability densities, not in terms of the absolute certainty of the outcome, just as in the traditional quantum measurement situation (e.g., compare the statement: “the scattered particle has x percent of chance to be detected in a given angular range”, as in a typical scattering problem, to the statement: “the quantum particle of a given momentum distribution has x percent of chance to be detected in a given spatial range”, as in a typical measurement problem). In the extreme case, even the non-perturbatively-treated unitary evolution situation can be regarded as a continuous branching-out of the probability densities, thus connecting smoothly to the scattering and the measurement problems. Therefore, the artificial division between the measurement problem and the unitary evolution problem is only a matter of perspective.

Another essential feature of the new ontological view is that the quantum mechanical wavefunction now specifies, instead of a wave of probability or potentiality, a realistic matter and energy distribution. It is only at the moment of quantum measurement, due to the abrupt nature of nonequilibrium phase transitions, that this underlying realistic distribution acquires a new format, with some “give-and-take” with the rest of the universe (Zhang 2007). These gives-and-takes with the rest of the universe underscore the entangled evolution of the entire matter and energy content of the universe, including the evolution of the biological entities from which consciousness emerges during the natural selection and evolution process.

### 3. NATURAL EMERGENCE OF CONSCIOUSNESS AND FREE WILL DURING THE COSMIC EVOLUTION OF THE UNIVERSE

In the new ontological model of the quantum processes we have summarized in the last section, the zeroth-order hierarchy of the processes in the quantum universe happen in a substratum of the continuous distribution of matter and energy content of the universe (Zhang 2007). There is an inherent chance or indeterministic factor in these processes. This chance factor in the zeroth-order hierarchy is not the same as what underlies the “Heisenberg uncertainty principle”: the latter in fact is a reflection of the distributed nature of quantum global modes, and the fact that the characteristics of these modes cannot be totally “pinned down” by simultaneous local measurements (Zhang 2007). The chance factor we are addressing here is rather related to the fundamental indeterminism in the phase transition of an infinite degrees-of-freedom open system (this is similar to the “butterfly effect” in a complex, nonlinear and chaotic system), and if we take the view that there is substantiality to the wavefunction itself, including substantiality to the phase of the wavefunction, then the source of this indeterminism becomes almost “classical” (with the understanding that such “quantum-classicality” refers to the lowest level in the hierarchy of phase transitions, and thus is not to be confused with true classical physics which deals with the higher-hierarchy physical processes).

In true classical physics, the nonequilibrium phase transitions happening in open, complex systems have been studied by the late Nobel laureate Ilya Prigogine and coworkers as the problem of the formation of “dissipative structures” (Prigogine 1984). It is well known that for an isolated system, the direction of entropy evolution is towards an increasing degree of macroscopic uniformity. For open systems at far-from-equilibrium conditions, however, it often happens that the usual thermodynamic branch of the solution (i.e. the one that leads to homogeneous distribution) becomes unstable, and new types of highly organized spatial-temporal structures emerge spontaneously. This kind of spontaneous structure formation in nonequilibrium systems has been termed “nonequilibrium phase transitions”, and the structures formed “dissipative structures” to emphasize the constructive role of dissipation in the maintenance of these nonequilibrium structures (this constructive role of dissipation also underlies the well-known “fluctuation-dissipation” theorem as applied to self-organized large-scale fluctuations). The large-scale coherent orders in open and nonequilibrium systems are functional as well as architectural. One of the important functions of these “dissipative structures” is to greatly accelerate the speed of entropy evolution of the parent nonequilibrium systems towards reaching equilibrium – even though for certain systems, such as those dominated by self-gravity, an ultimate thermodynamic equilibrium state does not exist. The rapidly-produced entropy by the dissipative structures is promptly exported out of the system as well, so locally the system could maintain a highly-organized structure without

violating the second law of thermodynamics (i.e., the fact that the local entropy production is increased does not contradict with the fact that the coherent, self-organized structure is maintained since the locally produced entropy by such a structure is exported out of the system. So locally the degree of randomness, which we usually associate with entropy, does not increase, and the organized structure can thus survive).

In this work, we propose that the emergence of biological beings – human beings included, can likewise be viewed as an instance of the formation of dissipative structures in the complex universe environment. In this case the ultimate source of subsequent nonequilibrium evolution lies in the low-entropy cosmic initial conditions. One distinguishing feature of the biological beings from other types of dissipative structures is the the gradual emergence of consciousness. One naturally wonders where lies the source of this distinguishing feature. In what follows, we will present our point of view in several steps.

First of all, it can be shown that all self-organized dissipative structures (including those in the inanimate world) behave “as if” they have a “mind”, i.e. these structures organize themselves spontaneously to optimize the achievement of their predestined mission of accelerating the entropy evolution of the parent nonequilibrium systems. In performing this function, these structures often appear to first “build a tool” by forming a complex, self-sustained morphological pattern which is capable of facilitating entropy production. For self-organized structures the more familiar type of causality law, i.e., that of local and sequentially-causal, has been changed to global and mutually-causal (or self-referential). When a complex nonlinear system forms a self-organized pattern, it in some sense has become “alive”.

An example in this regard is the spiral structure in disk galaxies such as our own Milky Way and the Whirlpool galaxy M51 (Zhang 1996, 1998; Zhang & Buta 2010). Spiral structures, which are density waves/modes in galaxies, satisfy many characteristics shared by other self-organized nonequilibrium dissipative structures. For example, a quasi-stationary spiral mode is maintained by the opposing effect of the spontaneous growth tendency and local dissipation, with a continuous flux of energy, angular momentum and entropy through the system carried by the spiral wave itself (Zhang 1998). It can also be shown that the formation of spiral structures greatly accelerates the speed of entropy evolution of a disk galaxy compared to that of a uniformly-rotating disk (the so-called “basic state”, whose characteristics form the boundary conditions for the emergence of self-organized spiral modes). A spiral mode is thus a global instability in the underlying basic state of the disk, and the spontaneous emergence of the spiral pattern out of an originally featureless, differentially rotating disk (which is obviously a global symmetry-breaking process) happens as long as the disk satisfies certain far-from-equilibrium constraints (i.e. the basic state characteristics, including the surface mass density distribution, the angular momentum distribution, and the

random velocity distribution of the disk-galaxy’s star and gas, must allow the linear growth rate of a spiral mode to be greater than zero). The pattern modal characteristics (spiral pitch angle, pattern speed, arm-to-interarm ratio) co-evolve with the underlying basic-state characteristics (i.e., the disk galaxy evolves from the more flattened type, or so-called late Hubble type, to the more rounded or centrally-concentrated type, or the so-called early Hubble type, with this evolution itself enabled by the spiral or bar pattern), since the modal characteristics need to be compatible with the boundary conditions set by the basic state.

If we regard biological entities also as “dissipative structures”, it is then natural to attribute part of the intelligence (or brain-like behavior) of higher biological beings to the inherent intelligence in the universal meta-laws governing the evolution of all dissipative structures. However, higher biological beings such as humans, besides possessing the common characteristics of all self-organized dissipative structures, including features appearing in inanimate systems, also possess the additional feature of free will (or intentionality). We define free will here as the capability to alter the predestined mechanical evolution of the universe through deliberate (rather than chance) manipulations by the originators of the free will. We argue here that free will is likely to be the main (or perhaps sole) distinguishing feature that separates higher biological beings from other types of dissipative structures. Other features that had previously been assigned competing roles in the definition of consciousness, such as self-awareness, or else the ability to behave in a manner that optimize its chance of survival, etc. – if we look deeper into what are involved in their functioning, all appear to have a closer kinship to equivalent functions in lower biological forms and in inanimate types of dissipative structures. Take self-awareness, for example. The operation of this feature first of all involves the definition of a self, or else a boundary separating the system from its environment. It is not hard to see that all self-organized dissipative structures can successfully be characterized with a boundary between the self and the environment. The “awareness” part of the characteristics is equivalent to a system’s ability to recognize (either the system or environmental) change, and to spontaneously coordinate its behavior to respond to the change, a characteristic once again satisfied by all self-organized dissipative structures. These systems also have the capability to transform themselves to best perform their predestined function of optimizing entropy production, and, in order to achieve this function, they can even “build a tool” to optimize their performance (i.e. through the self-organization process to build a dissipative structure). None of these functionalities require the presence of quantum interactions or the presence of biological entities.

Free will, or the ability to intentionally and deliberately manipulate the chance factor in the globally-connected quantum universe, on the other hand, does seem to be uniquely associated with biological beings, and with a biological evolution process that allows this ability to be gradually honed to perfection. Since the “will part” of the free will requires

a centralized command center for decision making, free will in its most developed form is likely to be possessed only by higher biological beings with a central processing unit such as a brain, although a less-developed form of chance manipulation should be present in lower biological forms as well. For free-will to be possible, the governing laws must be genuinely non-deterministic, in addition to results being non-predictable as in classical complex systems. The lowest-hierarchy phase transitions in the universe resonant cavity clearly satisfy the requirement of being non-deterministic, because of the singularity nature of the events originating out of an infinite degrees-of-freedom (or continuous) universe substratum.

The emergence of free will is likely to have involved a prolonged evolutionary process: from chance manipulation of degrees-of-freedom in the continuous substratum by the primordial forms of biological beings (including single-celled organisms), through intermediate-complexity biological forms in the tree-of-life (those that straddle the boundary between operating through conditioned-reflexes, and deliberate contemplation and decision-making), and finally arriving at its highly-developed form in humans and other mammals. It is thus likely that the emergence of human-type consciousness is both pre-programed in the meta laws of the evolving universe, as an extreme form of the intelligence inherent in the functionality of dissipative structures, and also facilitated by the natural selection process.

#### 4. INSIGHT FROM EASTERN MEDICAL PRACTICES AND PARANORMAL PHENOMENA

Our current view on the origin and nature of consciousness presupposed that consciousness is an emergent property of the evolving and interconnected universe. It is evolved from a low-level pan-conscious state of lower biological forms, which learned and perfected the skill to manipulate the chance factor in the global phase transitions in the quantum universe. In this section we look more closely at the functioning of the human body as revealed by certain eastern medical and spiritual practices, as well as at certain paranormal phenomena, to seek support for this scenario of the gradual evolution of consciousness and its connection with the universe environment.

First we note that the existence of a meridian system in the human body has been known for thousands of years in Chinese medicinal practice and is the basis of the accupuncture and accupressure. The physical manifestations of the human meridian system have been confirmed by various modern experiments as channels of low resistivity, as well as locations for distinctive sound response upon abrupt impact, even though no anatomical features of this system can be visually discerned – it is in some sense not unlike the economic forces penetrating a society even though not everything can be perceived in a concrete form. During



acupuncture practice, as needle pressure is applied to a specific accupuncture point on the meridian, this location becomes a temporary “command center”, coordinating the responses from other parts of the body, with signal traveling routes along the meridian system, thus opening up blocked pathways and invigorating the functioning of the relevant organs. Similar flow of energy (or “chi”) can be induced by meditation practices in Hinduism, through focusing on successive “chakras” on the body and thus enhancing the connectedness of the person as a whole. These phenomena suggest that self-organized intelligent behavior can be induced in biological entities without the coordinating role of the brain – as must have been the case if consciousness is the product of gradual evolution from lower biological forms which did not at first possess a central nervous system. Consciousness thus originates as a distributed property of lower biological forms (as is the case for the intelligence possessed by inanimate dissipative structures), and traces of these characteristics still manifest in the functioning of the highly-developed human body even though now the brain and the central nervous system appear to dominate.

Much of the “subconscious” or “unconscious” decision-making processes in human beings involve the substantial participation of the rest of the body. Much of the human autonomous nervous system is known to be able to function without the direct interference of the central nervous system (in fact, much of the autonomous system’s function can be disrupted if the brain exercises excessive control – i.e. one’s stomach can become upset if one is overly nervous, that is the time we usually tell the person to relax, and to let the body own intelligence to take over without the interference of the mind or the will) . It is in fact tempting to speculate that the role of the brain (including its multitudes of neuron firings) is rather like the role of the government in a country: it is the executive branch doing the job of running the show, and yet the source of its intelligence, i.e., the seat of consciousness, runs much deeper. In our view, the ultimate source of consciousness lies in how the different components of our body (including all the cells and genes) inter-relate and interact, and how they are coupled to the universe environment and to the irreversible evolution of this environment. Compared to inanimate self-organized structures such as spiral galaxies or atmospheric convection cells (the Benard instability), the human body is a highly-developed form of spatial-temporal dissipative structure that is constructed according to quantum-mechanical laws. The entangled quantum interaction allows the instantaneous access of human consciousness to resources that are considered separate and inaccessible by mechanical (or classical) interactions alone. This view of consciousness thus leaves open the door for the explanation of various paranormal and savant behaviors, since the ability to harness the entangled global resources can conceivably be naturally gifted to certain fraction of the human population, or be enhanced though deliberate training.

## 5. IMPLICATIONS ON ARTIFICIAL INTELLIGENCE AND THE FUTURE OF BIOLOGICAL EVOLUTION

Another implication of the current proposal is that there can be no self-aware mechanized artificial intelligence no matter how advanced the technology becomes, since biological intelligence is evolved as part of interconnected universal evolution. A mechanical computer’s CPU will never acquire free will, since it will never be able to establish the infinite multitudes of connections with the rest of the universe environment (a web of connections linking all matter and energy in the universe, initiated and evolving together since the time of the Big Bang), including entanglement in the phases of the wavefunctions (the Aharonov-Bohm effect). However, entities formed through semi-biological pathways, such as cloning, are possible because they tap into nature’s established pathways to establish these infinite connections.

Recently, the IBM computing machine “Watson” has generated a lot of press coverage with its stellar performance on the Jeopardy show. One naturally wonders that given another several hundreds years, whether machines like Watson can be made smart enough to “think”, to be “conscious” (with an inner awareness), and to possess “free will”. Our answer to these speculations is once again No. To see why this is so, recall that consciousness in our view is an emergent property in the universe environment. All emergence properties share the characteristics that it is a kind of “modal” property of the underlying system. You can excite the mode through different types of perturbations, but the kind of mode that eventually stabilizes for given boundary condition is highly reproducible (that is why these modes are called the “intrinsic modes” of the underlying system). Similar statements can be made for biological entities under this scenario. We are not accidents in this universe. The characteristics of the universe predetermined the gross characteristics of our beings even though the details of the events happening around us are affected both by randomness and by the intervention of our own free will. A machine like Watson can be invented by IBM with one type of internal organization, and by others in a European company with a different type of internal organization. Both may manifest the same functionality, but the organizations are up to the choice of inventors: it is not a product of spontaneous creation of the universe and not an inevitable element of its continuous evolution. Another drastic difference between a computing machine and a biological entity is that a machine is not fundamentally a “dissipative structure” (translates to “nonequilibrium spatial-temporal mode”), and its functioning is not regulated by a continuous flux of entropy and energy through it. In that sense a computer, no matter how intelligent it appears to be (the appearance caused by the pre-injected human intelligence), and how well it can emulate humans, is fundamentally even less intelligent (or less “alive”) than a spiral galaxy, in that it is not dynamically coupled to the environment, and thus cannot naturally adjust its

morphological and dynamical characteristics as the environment changes (i.e., as the universe evolves).

This view of consciousness as an emergent property of the entire biological being also alleviates usual concerns for quantum decoherence (Tegmark 2000). Consciousness as a self-organized, organism-wide phenomenon is in constant exchange and in dynamical equilibrium with its environment. The decoherence and dissipation tendency is naturally opposed by the self-organization tendency of naturally-selected resonant modes (i.e., we regard biological entities and their associated conscious behaviors all as modal characteristics in the evolving universe resonant cavity). The functioning of a higher biological entity involves the intricate web of simultaneously occurring quantum chemical processes, none of these can be viewed as strictly unitary or strictly measurement processes, but are organized in a global hierarchical fashion by nature, perfected during the long history of evolution process.

The recent discovery in the wave-like coordinated behavior in photosynthesis processes (see, e.g., Engel et al. 2007, Collini et al. 2010) provides another piece of evidence that quantum self-organized global patterns may be a common underlying feature in all types of biological processes. Other characteristics of the biological-entities' functioning, such as magnetic navigation capability in migrating birds, a growing plant's ability to sense gravity, light source and seasons, the developing embryo's ability to decode the DNA information and to assemble complex organs and tissues and to make these structures function harmoniously in the natural environment, all point to the connected unfolding of biological entities program in an intimately participating universe. The role of consciousness is not a one-way street, as the brain exercises its free will to shape the world. The changing environment also applies its influence on the continued rewiring of the brain as well as the continued renewal of the evolving biological species.

The idea of consciousness emerging as a natural process in the quantum universe also means that consciousness does not perform the unique role of "collapsing the wavefunction" as proposed in certain quantum measurement theories. In this regard consciousness merely joins a multitude of other natural mechanisms in participating in global nonequilibrium phase transitions. The uniqueness of consciousness lies in its highly-evolved ability to tap into the non-deterministic potentiality of global phase transitions so as to make the carriers of consciousness (i.e. human beings and other higher biological forms) able to optimally perform their predestined function of accelerating the entropy evolution of the universe.

## REFERENCES

- Collin, E. et al. 2010, “Coherently wired light-harvesting in photosynthetic marine algae at ambient temperature,” *Nature*, vol. 463, p. 644
- Engel S. et al. 2007, “Evidence for wavelike energy transfer through quantum coherence in photosynthetic systems,” *Nature*, vol 446, p.782
- Neuenschwander, D.E., 2010, “Emmy Noether’s Wonderful Theorem” (The Johns Hopkins University Press)
- Penrose, R., Shimony, A., Cartwright, N., & Hawking, S. 1997, “The large, the small, and the human mind”, (Cambridge: CUP)
- Prigogine, I. 1984, “Order out of Chaos” (Shambala)
- Sakurai, J.J. 1985, “Modern quantum mechanics” (Addison-Wesley)
- Stapp, H.P., 2009, “Mind, matter, and quantum mechanics,” 3rd edition (Berlin: Springer)
- Tegmark, M. 2000, “Importance of quantum decoherence in brain processes,” *Phys. Rev. E*, 61, 4194
- Zhang, X. 1996, “Secular evolution of spiral galaxies. I. A Collective Dissipation Process,” *The Astroph. J.*, vol. 457, p. 125
- Zhang, X. 1998, “Secular evolution of spiral galaxies. II. Formation of quasi-stationary spiral modes,” *The Astroph. J.*, vol. 499, p. 93
- Zhang, X. 2007, “On the nature of quantum phenomena”, <http://arxiv.org/abs/0712.4297>
- Zhang, X., & Buta, R.J. 2010, “Density-wave induced morphological transformation of galaxies along the Hubble sequence” (<http://arxiv.org/abs/1012.0277>)